Melbourne City Council (CH2)

# Air Conditioning Design Strategy

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Melbourne City Council

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design advice

passive systems

design analysis

low energy services

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# EXECUTIVE SUMMARY


This report has been prepared by Advanced Environmental Concepts as part of the design process for the new Melbourne City Council (MCC) offices which recognises the increasing concern for the environment through adopting Ecologically Sustainable Development (ESD) practices.

A green building is a sustainable and healthy building for its occupants and the environment. An important aspect in the design of green buildings is energy usage which affects carbon emissions. Carbon emissions are affected by the energy consumed by the base building (central services and common areas) and its tenants.

A building's air conditioning system is typically responsible for around 50% of the base building's energy consumption. The other 50% typically includes other services such as common area lighting, domestic hot water, lifts, etc. As such, any reduction in air conditioning energy consumption or efficient energy utilisation will offer significant savings in total building energy consumption and carbon emissions.

In response to the above, this report will examine the air conditioning system to be adopted by Melbourne City Council House through the separate analysis and assessment of initiatives and their effects on the air conditioning system

A base model will be used to represent a standard air conditioning system, and through comparative analysis, initiatives will be assessed. Initiatives include the use of night purging, displacement air flow, chilled ceilings/beams, 100% fresh air intake, phase change materials, and a co-generation plant. Analysis will mainly include the building's energy consumption, energy utilisation and carbon emission reduction. All models will also be compared to a 4.5 star Australian Building Greenhouse Rated building.

It is recommended that, based on the results of this report, that night purging, displacement ventilation, chilled ceilings/beams, 100% fresh air intake, phase change materials and a co-generation plant be adopted to significantly contribute to the health of occupants, the reduction of carbon dioxide emissions and reduce energy consumption of the building.

The use of all these initiatives will reduce carbon emissions to 44% of a 4.5 star Australian Building Greenhouse Rated building. This is expected to reduce even further with the adoption of LCD flat screen monitors which reduce cooling loads by 12% and reduce the building's energy consumption.

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| **Date** | **7 May 2003** | |
|---|---|---|
| Revision and Status | Final | |
| Author | Su-fern Tan | |
| Project Team Leader | Mark Cummins | |

## LIST OF FIGURES

# 1 INTRODUCTION

This report presents the approach, results, conclusions and recommendations for the analysis carried out to propose a best practice air conditioning system with efficient energy consumption and reduced greenhouse gas emissions.

The Approach section will discuss how we begin the study by first examining the loads on the building when it is complete and occupied. This provides a guide to the heating or cooling loads required to be met throughout the year, to maintain air and temperature levels for comfort. Each model built for analysis will also be discussed in this section.

The Results and Discussion section will show the results and analysis of the modelling which will form the basis of our Conclusions and Recommendations section. The different systems modelled will be rated based on their energy consumption, and carbon dioxide emissions compared to a 4.5 star rated building.

# 2 APPROACH

Thermal Analysis Software (TAS) was used to create an accurate three-dimensional thermal model to assess the performance of the building. The model uses current building design, and performs dynamic building simulation and calculations from which an accurate analysis can be undertaken.

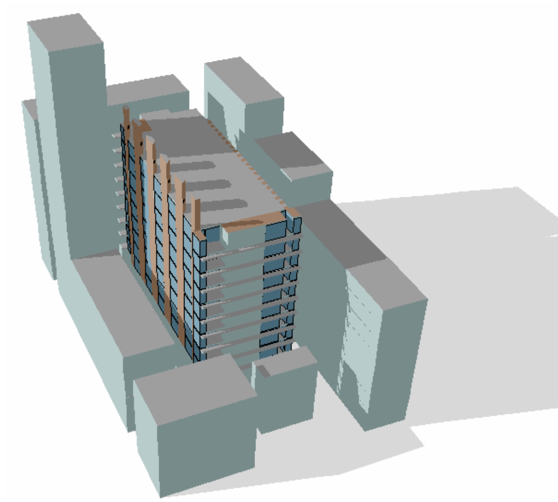

Figure 1. The 3D TAS Model used for analysis

## 2.1 Models

The first model built represents the MCC offices using a conventional, good practice, variable air volume (VAV) air conditioning system which relies on the mixing of room air. Such a system is typical for most grade 'A' buildings within Australia. This model will act as a base model for our analysis.

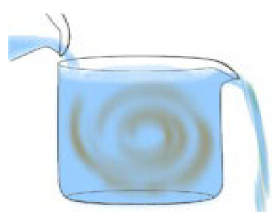

Figure 2. Mixed air distribution in a VAV system

The second model represents the MCC offices using the previously modelled VAV system with night purging ventilation. The night purge system occurs when windows automatically open at night if the outside air is cool enough to naturally cool down the building via cross ventilation. This model will show if there are any benefits using a night purge strategy.

The third model uses the second MCC model and adds displacement air flow to the building. Displacement air flow allows air at different temperatures to move from an entry point ie cold air from supply air floor grills, to an exit point ie exhaust air slots in the ceiling. This means that supply and exhaust air does not keep mixing but instead follows a one way flow path. The third model shows if there is a benefit in a displacement air flow strategy.

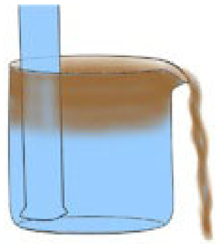

Figure 3. Displacement ventilation air layering effect

The fourth model makes one change to the third model by adopting a chilled ceiling/beam system for space cooling, and thus replaces the VAV system. The fourth model was created to show if there are benefits to a chilled ceiling air conditioning system.

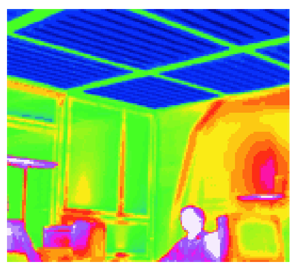

Figure 4. Chilled ceilings radiant cooling effects

The fifth model uses phase change materials (PCMs) in conjunction with shower/cooling towers to provide cooling chilled ceilings/beams instead of using electric chillers. This model will show the PCM’s contribution to the reduction in electricity consumption.

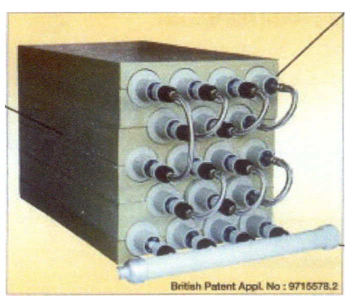


Figure 5. Example of a phase change (PCM) module. Source PCI.

The sixth and final model uses waste heat from a gas powered co-generation plant to provide a significant amount of energy required for heating and/or cooling fresh air entering the space. The final model will show if there are any benefits in energy consumption by using a co-generation plant.

## 2.2 Zones

For each model, the floor plan has been divided into five zones which each have different heating and cooling requirements. The zones are

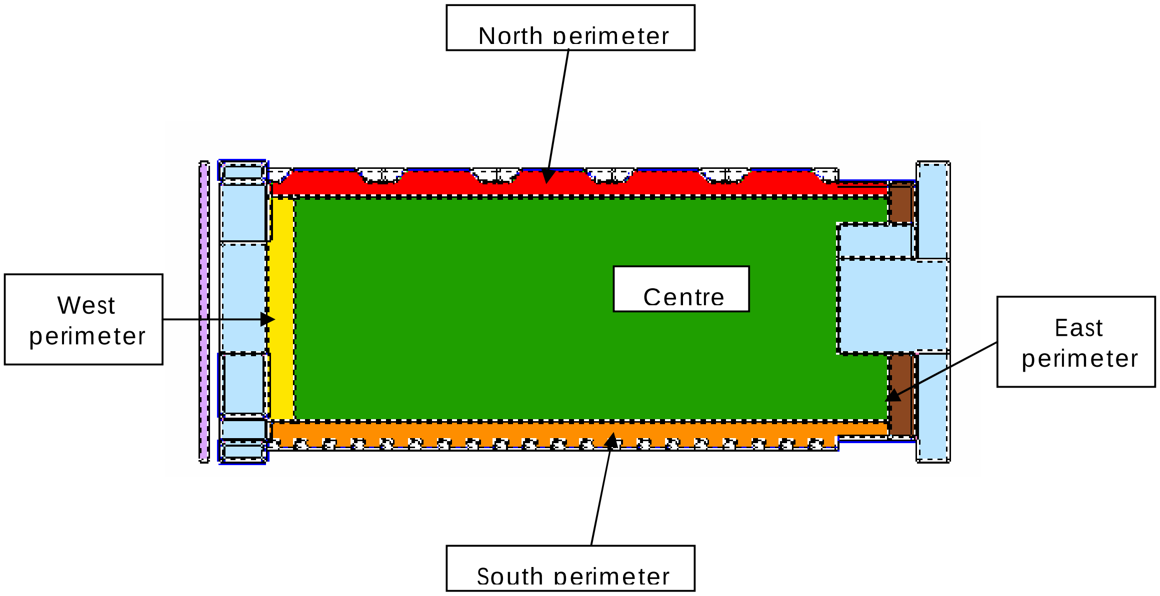


Figure 6. Zones in floor plan

## 2.3 Building Loads

Building loads determine the heating and cooling requirements of a building and come from sources such as occupants, equipment, lighting and the sun.

The following graph shows building loads over a 24 hour period on the new MCC office building and solar loads for typical summer, mid-season and winter days.

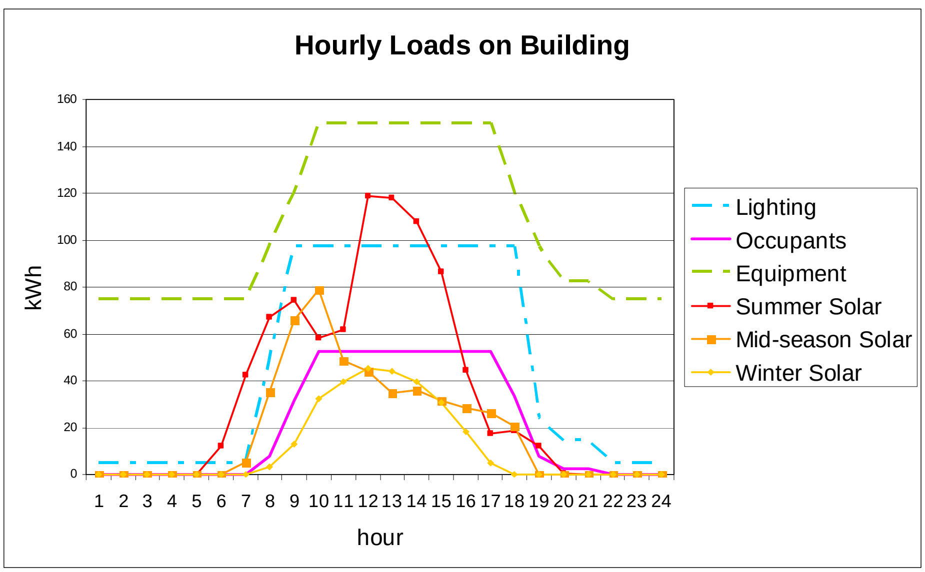


Figure 7. Hourly building loads

For office buildings like the new MCC offices, lighting, occupant and equipment loads are constant throughout the year on working days. Solar loads will vary daily and depend on seasonal and weather conditions.

The heating and cooling requirements of a building depend on the loads placed on that building.

## 2.4 Heating and Cooling Requirements

The amount of energy which must be supplied or removed by the air conditioning system in order to maintain comfort are called the heating and cooling loads.

The following graph shows the monthly heating and cooling loads for the whole building. These results assume there is no night purge occurring and like all models, the air conditioning system operates from 7am until 6pm.

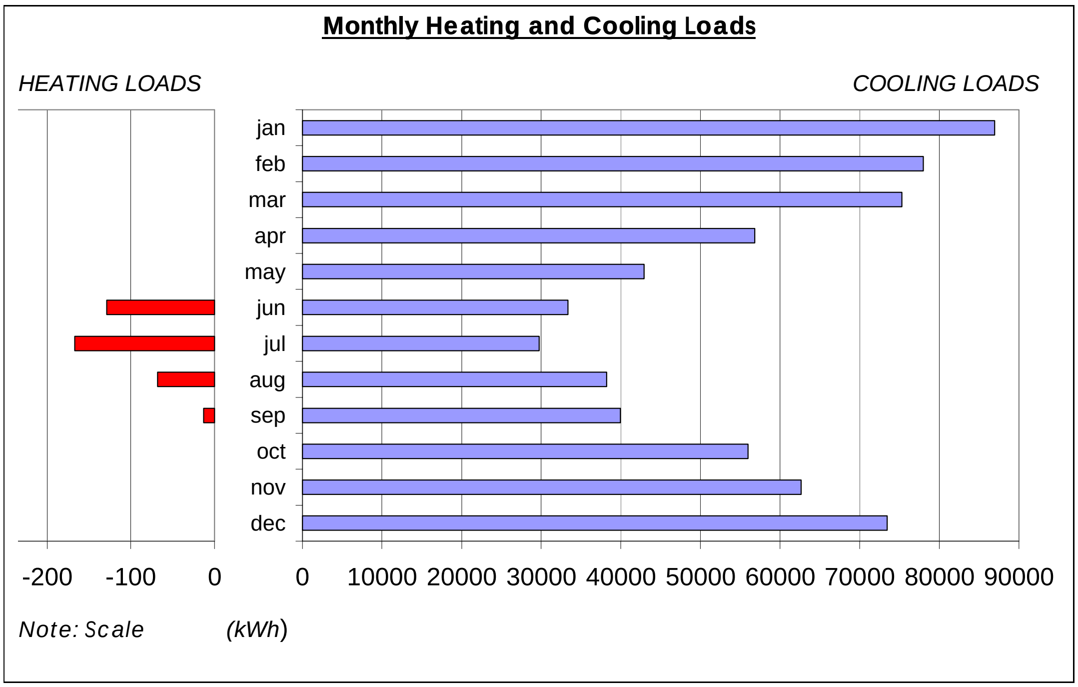


Figure 8. Monthly breakdown of heating and cooling requirements of total building

It is apparent that the building will require very little heating during colder months, and a significantly large amount of cooling throughout the year due to constant solar and internal load gains.

Heating and cooling requirements can also be viewed on a per zone basis which facilitates efficient air conditioning design. For example, the centre zone will have totally different cooling requirements to the west perimeter and trying to control the temperature in both of these zones from the same air supply is neither efficient nor very effective.

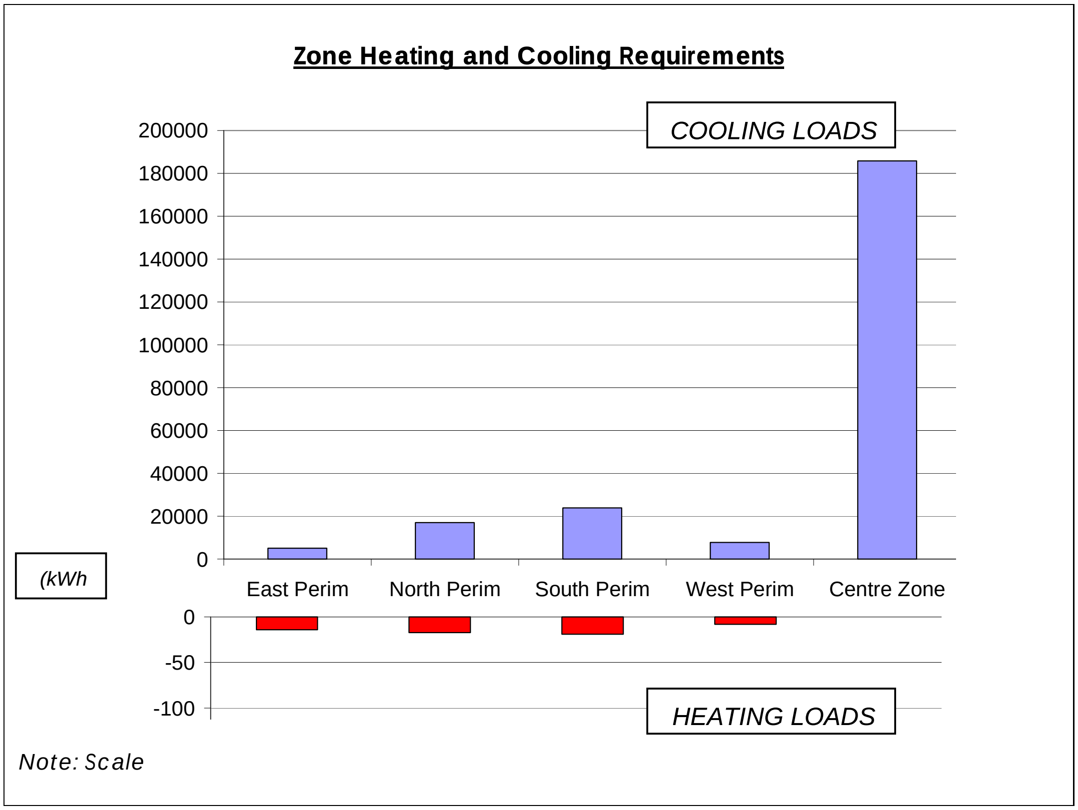


Figure 9. Zone breakdown of heating and cooling requirements

The building is dominated by cooling loads and not heating loads. Furthermore, we can see that the cooling load on the building is largely driven by the centre zone.

The next graph shows the proportion of cooling requirements for the building in each zone.

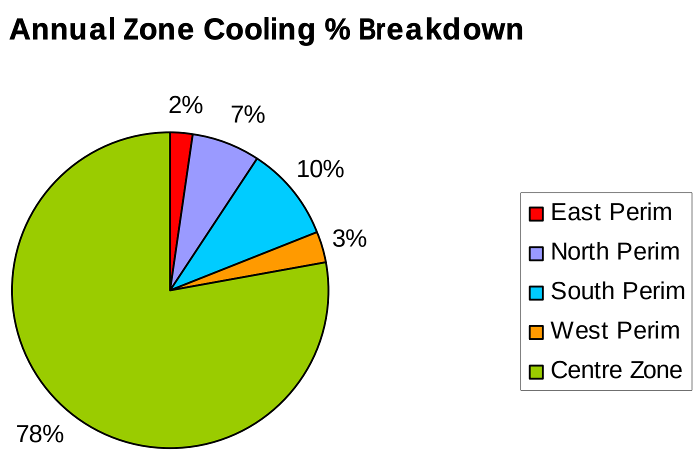


Figure 10. Zone cooling percentage breakdown

The following analysis will look at the options adopted for air conditioning and examine their contribution to the reduction in energy consumption whilst still satisfying heating and cooling requirements.

# 3 RESULTS

## 3.1 Base Model

- Good practice VAV (variable air volume) air conditioning system

This model uses a VAV air conditioning system which divides the floor plan into north and west perimeters, south and east perimeters, and the centre zone.

The air entering the office area will be a mixture of minimum fresh air requirements and re-circulated air from the space. This mixed flow distribution is the traditional method of supplying air. Cool air is blown in through the ceiling and dilutes the room air to provide an even temperature and contaminant level through the space.


Figure 11. VAV system mixed air distribution

The following graph will shows the loads placed on the main components of the air conditioning system. We can see that the gas boiler is used only in the colder months, that fan consumption is constant throughout the year, and that the chillers work harder from November through to May during the warmer months.

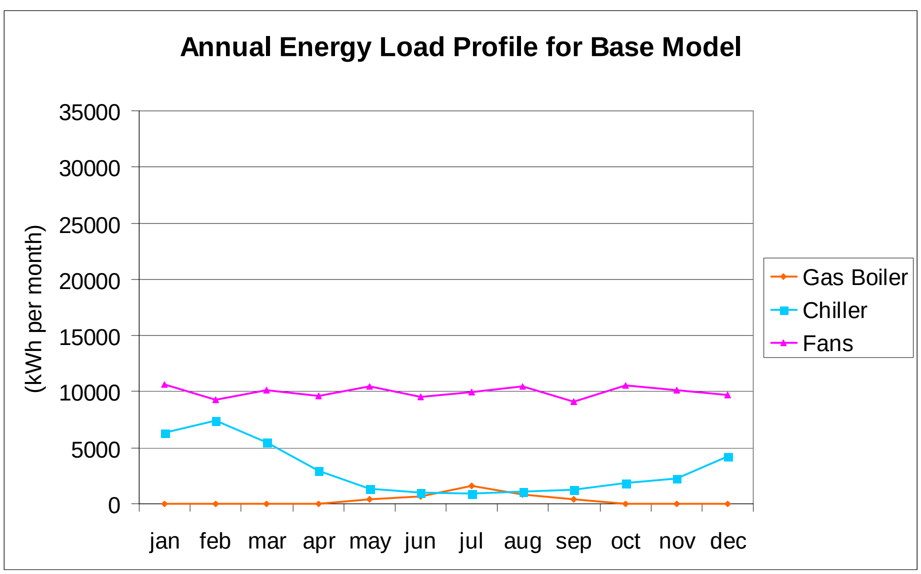


Figure 12. Annual energy load profile for the base model

Following, is a table detailing predicted annual energy consumption of the base model.

| Month | Gas Boiler Input (kWh) | Chiller Input (kWh) | Fans AHU (kWh) | Fans Cool Tower (kWh) | Elec Reheat (kWh) | Water Pumps Chilled (kWh) | Water Pumps Hot (kWh) | Total (kWh) |
|---|---|---|---|---|---|---|---|---|
| jan | 0 | 6343.5 | 10646.9 | 603.9 | 0 | 2415.4 | 0 | 20009.7 |
| feb | 0 | 7382.5 | 9260.5 | 708 | 0 | 2832.1 | 0 | 20183.1 |
| mar | 0 | 5456.9 | 10155.8 | 565.7 | 0 | 2263 | 0 | 18441.4 |
| apr | 0 | 2954.9 | 9633.1 | 308 | 0 | 1231.8 | 0 | 14127.8 |
| may | 429.5 | 1342.8 | 10488.2 | 111.8 | 0 | 447.2 | 4.9 | 12394.9 |
| jun | 704 | 1022.4 | 9558.4 | 84.9 | 0 | 339.7 | 7.7 | 11013.1 |
| jul | 1637 | 936.4 | 9989.7 | 77.8 | 0 | 311.1 | 23.3 | 11338.3 |
| aug | 812.2 | 1128.8 | 10494.8 | 93.7 | 0 | 375 | 9.8 | 12102.1 |
| sep | 449.1 | 1256.9 | 9142.4 | 108.7 | 0 | 434.9 | 5.2 | 10948.1 |
| oct | 15.6 | 1885.4 | 10562.9 | 174.1 | 0 | 696.2 | 0 | 13318.6 |
| nov | 0 | 2306.2 | 10123.8 | 222.2 | 0 | 888.9 | 0 | 13541.1 |
| dec | 0 | 4183.5 | 9708.5 | 422.7 | 0 | 1690.9 | 0 | 16005.6 |
| **Annual Total** | **4,047** | **36,200** | **119,765** | **3,482** | **0** | **13,926** | **51** | **173,424** |

Figure 13. Estimated annual energy consumption for base model

An economy cycle has been included with a high enthalpy cut-out optimised for the Melbourne climate. Electric re-heat is provided to the perimeter zones, and heat is rejected via wet cooling towers.

Outside air requirements are 10L/s per person and minimum air circulation rates are 6L/s per person for perimeter zones and 4.5L/s per person for centre zones.

| | | | |
|---|---|---|---|
| Total electric consumption | = | 173 424 | kWh |
| Total gas consumption | = | 36 200 | kWh |
| $CO_2$ emissions | = | 233 238 | kg |

## 3.2 Night Purge Model

- Base model + night purging

In a building with high levels of exposed thermal mass and an open floor plan, like the new Melbourne City Council House, it is possible to utilise natural ventilation throughout the night in order to cool down the thermal mass in the building. The differences between night and day time temperatures also vary enough in Melbourne to enable natural cooling effects to occur.

In the morning, when the air conditioning plant turns on, the building is closed up and heat gains begin to increase due to internal and solar loads. If we cool down the thermal mass of the building interior at night, these cool internal surfaces can absorb some heat and lower internal radiant (surface) temperatures during the day, which will reduce the cooling demand on the building.

This model incorporates an automated night purge ventilation system into the base model which will enable us to see the effects of night purging on energy consumption.

The controls for windows are based on outside air temperatures being between 19° - 21°C, and wind speeds under 5m/s. The free window area deemed optimum was calculated to be 1% of total floor area (approximately 25m$^2$ of free window area per floor).

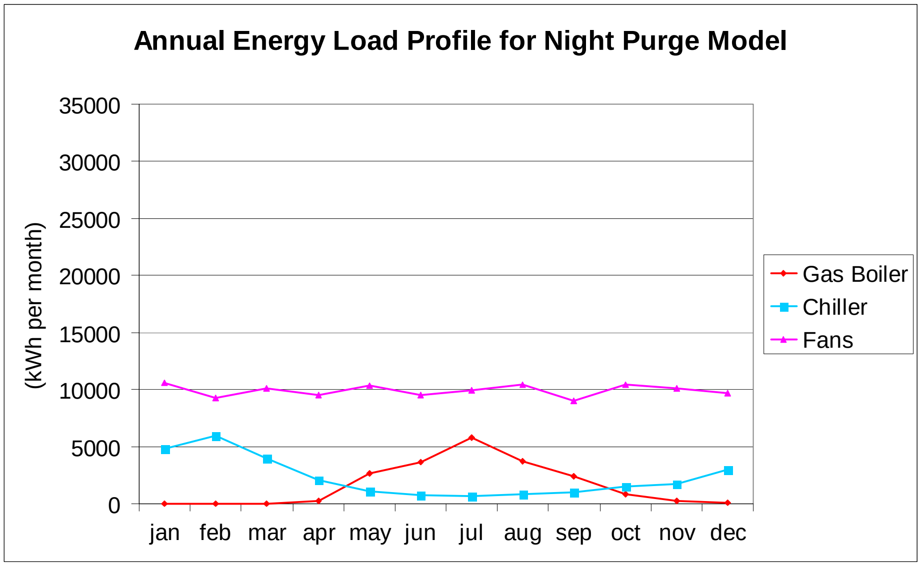


Figure 14. Estimated annual energy load profile for the night purge model

The annual energy load profile graph shows a significant decrease in the chiller load, and thus in total electric consumption. Night purging has successfully allowed the building to cool down considerably and reduce the cooling load on the building.

We can also see that the gas consumption for the boiler has increased in winter because cold fresh air entering the building at night cools the thermal mass which may need some heating during colder mornings. Night purge parameters can be fined tuned at a later stage in the project to reduce heating loads even further.

| Month | Gas Boiler Input (kWh) | Chiller Input (kWh) | Fans AHU (kWh) | Fans Cool Tower (kWh) | Elec Reheat (kWh) | Water Pumps Chilled (kWh) | Water Pumps Hot (kWh) | Total (kWh) |
|---|---|---|---|---|---|---|---|---|
| jan | 15.6 | 4783.8 | 10631.4 | 449.9 | 0 | 1799.7 | 0 | 17664.8 |
| feb | 0 | 5955.9 | 9256.4 | 546 | 0 | 2184 | 0 | 17942.3 |
| mar | 0 | 3958.6 | 10096.3 | 409.1 | 0 | 1636.3 | 0 | 16100.3 |
| apr | 250.9 | 2074 | 9544.5 | 218.4 | 0 | 873.5 | 3.2 | 12713.6 |
| may | 2610.5 | 1064.1 | 10381.8 | 88.5 | 0.1 | 353.9 | 40.6 | 11929 |
| jun | 3616 | 747.5 | 9477.8 | 62.1 | 1.4 | 248.3 | 56.6 | 10593.7 |
| jul | 5815.9 | 652 | 9932.1 | 54.1 | 0.1 | 216.6 | 93.9 | 10948.8 |
| aug | 3690.6 | 826.7 | 10430.7 | 68.7 | 0.9 | 274.6 | 57.4 | 11659 |
| sep | 2364.7 | 973.8 | 9040.2 | 83.4 | 0 | 333.6 | 36.8 | 10467.8 |
| oct | 810 | 1478.3 | 10458.3 | 135.5 | 0 | 542.1 | 11.4 | 12625.6 |
| nov | 241.4 | 1712.4 | 10054.6 | 165 | 0 | 660 | 2.4 | 12594.4 |
| dec | 68 | 2958.7 | 9653.6 | 305.4 | 0 | 1221.8 | 0.3 | 14139.8 |
| **Annual Total** | **19,484** | **27,186** | **118,958** | **2,586** | **3** | **10,344** | **303** | **159,379** |

Figure 15. Estimated annual energy consumption for night purge model

| | | | |
|---|---|---|---|
| Total electric consumption | = | 159 379 | kWh |
| Total gas consumption | = | 19 484 | kWh |
| $CO_2$ emissions | = | 217 660 | kg |

### 3.3 Displacement Ventilation Model

- Night purge model + displacement ventilation

Displacement ventilation introduces air at low level and low velocity into a space. Through natural convection, heated air moves upwards. Gravity enables the formation of thermal layers from floor to ceiling which separates clean cool air from contaminated warm air. Warm air from heat sources lift up through occupied zones and gets relieved at high levels.

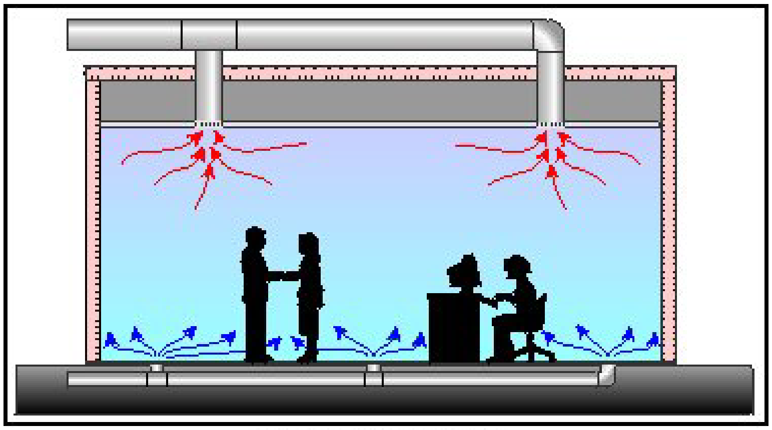

Figure 16. Displacement ventilation effects

Displacement ventilation also reduces energy costs because the velocity and temperature of supply air is much lower.

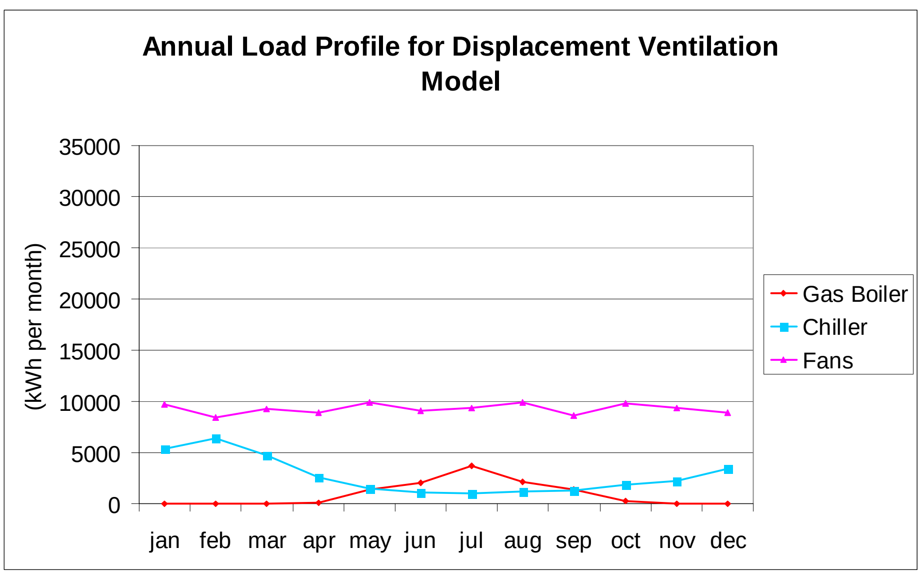


Figure 17. Estimated annual energy load profile for the displacement ventilation model

Due to the increased amount of fresh air entering the occupied space, the boiler load has increased during the colder months as more cold air needs to be constantly heated to the required design levels.

Electricity consumption has decreased because supply air requirements are much less demanding. Air is introduced into the space at around 0.2m/s or less, usually through floor vents at 1- 2°C below desired temperature levels. In comparison, the

VAV system needs to cool supply air at 6 - 10°C below desired temperature levels with a velocity of around 2.5m/s.

| Month | Gas Boiler Input (kWh) | Chiller Input (kWh) | Fans AHU (kWh) | Fans Cool Tower (kWh) | Elec Reheat (kWh) | Water Pumps Chilled (kWh) | Water Pumps Hot (kWh) | Total (kWh) |
|---|---|---|---|---|---|---|---|---|
| jan | 0 | 5357.5 | 9702.8 | 500 | 0.8 | 1999.9 | 0 | 17,561 |
| feb | 0 | 6419.8 | 8442.5 | 597.1 | 0 | 2388.2 | 0 | 17,848 |
| mar | 0 | 4700.8 | 9281.5 | 477.8 | 0.7 | 1911.4 | 0 | 16,372 |
| apr | 85.9 | 2638.8 | 8919.2 | 272.3 | 5.1 | 1089.1 | 1 | 12,926 |
| may | 1380.1 | 1440.7 | 9875.4 | 120.4 | 17.7 | 481.6 | 21.9 | 11,958 |
| jun | 2037.4 | 1069.6 | 9032.2 | 88.8 | 0 | 355.3 | 32.7 | 10,579 |
| jul | 3740.3 | 1020.6 | 9390 | 84.8 | 2.4 | 339 | 61.5 | 10,898 |
| aug | 2097.6 | 1239.4 | 9891.4 | 102.9 | 5.6 | 411.7 | 33.5 | 11,685 |
| sep | 1414.6 | 1325.4 | 8596.4 | 114.2 | 3 | 456.8 | 22.6 | 10,518 |
| oct | 299.6 | 1854.6 | 9845.8 | 171.6 | 14.2 | 686.5 | 3.9 | 12,577 |
| nov | 28.2 | 2202.8 | 9331.8 | 208.8 | 10.9 | 835.4 | 0.4 | 12,590 |
| dec | 0 | 3417.5 | 8866.5 | 348.9 | 0.3 | 1395.4 | 0 | 14,029 |
| **Annual Total** | **11,084** | **32,688** | **111,176** | **3,088** | **61** | **12,350** | **178** | **159,539** |

Figure 18. Estimated annual energy consumption for displacement model

| | | | |
|---|---|---|---|
| Total electric consumption | = | 159 539 | kWh |
| Total gas consumption | = | 11 084 | kWh |
| $CO_2$ emissions | = | 216 110 | kg |

### 3.4 Chilled Ceilings Model

- Displacement ventilation model + chilled ceilings and beams

Chilled ceilings and beams use the simple concept of providing cooling using water to transport heat, not air. The space is cooled through radiant and convective exchange where heat is exchanged between surfaces of differing temperatures, and cool air descends freely from the ceilings and beams instead of being blown into the spaces by fans.

Ceiling surfaces are normally in the range of 15-18°C which provides a much more pleasant radiant cooling effect for people with minimal air movement and also provides a cleaner and natural indoor climate for occupants.

Cost benefits of chilled ceiling and beam systems include:

1. *Space saving* on high volume ductwork which minimises ceiling void requirements, saves on building costs, and provides increased refurbishment performance and opportunities.
2. *Energy efficiency*. Unlike in original ductwork systems, there are no friction losses to compensate for, lagging is virtually eliminated and often the fabric of the building contributes to the cooling system. The reduction of plant required also reduces energy consumption and greenhouse gases emission.
3. *Increased productivity*. Due to increased air quality standards, comfort and performance of occupants is increased. Cooling is provided evenly, there is no risk of draughts, and the system is much quieter than conventional systems.

4. *Maintenance and life expectancy*. The absence of moving parts generally within the system substantially reduces maintenance requirements which play a significant part in the total cost of the system, and its life expectancy.

Figure 19. Example of chilled ceiling panel. Source BSEE

This model incorporates into the previous displacement model, a chilled ceiling cooling system for the centre zones, and chilled beams for the perimeter zones. This model will show the effects of changing the cooling system. Fresh air requirements and air re-circulation parameters remain the same as the previous model.

Using chilled ceilings/beams and displacement air ventilation splits cooling/heating requirements and fresh air requirements into 2 separate systems. With the previous VAV system, cool air blown into the space handled both cooling/heating and fresh air requirements.

Heating will be provided at floor level via convective fin elements powered by a central gas fired boiler, and the chilled ceilings/beams are powered by a central electric chiller. A separate air handling unit will be also powered by the central gas boiler and electric chiller. In addition, air introduced to the space is de-humidified to ensure that there is no risk of condensation on the ceiling panels.

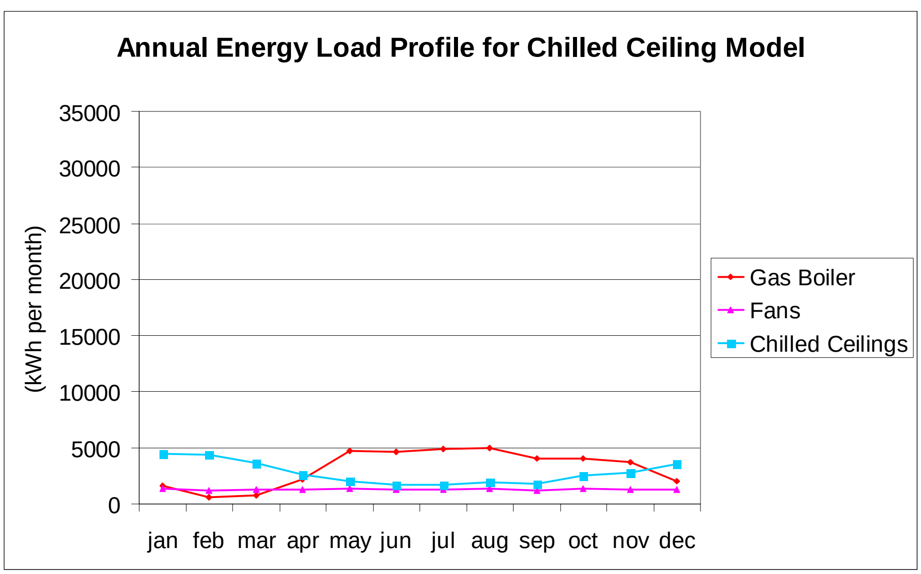


Figure 20. Estimated annual energy load profile for chilled ceiling model

We can see that fan consumption has significantly decreased along with chiller consumption meaning that the total amount of electricity needed by the system has been drastically reduced. Gas consumption has increased very slightly due to the de-humidification of warm air in summer. Compared to the last model, we can also see that gas consumption is more evenly spread during winter, at a lower energy consumption level, and less erratic due to the change of cooling system.

| Month | Gas Boiler Input (kWh) | Chiller Input (kWh) | Fans | | Elec Ceiling Chiller (kWh) | Water Pumps | | Total (kWh) |
|---|---|---|---|---|---|---|---|---|
| | | | AHU (kWh) | Cool Tower (kWh) | | Chilled (kWh) | Hot (kWh) | |
| jan | 1580.8 | 1934.1 | 1349.3 | 623.6 | 4467.2 | 4988.6 | 25.3 | 13388.1 |
| feb | 628 | 2718.4 | 1173.3 | 663.7 | 4410.6 | 5309.8 | 10 | 14285.8 |
| mar | 762.7 | 1845.3 | 1290.6 | 558.5 | 3592.1 | 4467.7 | 12.2 | 11766.4 |
| apr | 2212 | 442.8 | 1231.9 | 346.4 | 2595.6 | 2771.1 | 35.4 | 7423.2 |
| may | 4717 | 41.6 | 1349.3 | 251.5 | 2040.9 | 2011.9 | 75.5 | 5770.7 |
| jun | 4651.4 | 16.4 | 1231.9 | 201.1 | 1688.9 | 1608.8 | 74.4 | 4821.5 |
| jul | 4875.8 | 34.8 | 1290.6 | 192.7 | 1674.6 | 1541.3 | 78 | 4812 |
| aug | 4975.5 | 2.8 | 1349.3 | 237.8 | 1958.8 | 1902.4 | 79.6 | 5530.7 |
| sep | 4023 | 19.1 | 1173.3 | 222 | 1791.7 | 1776.1 | 64.4 | 5046.6 |
| oct | 4085.9 | 90.7 | 1349.3 | 318.5 | 2493.3 | 2548.3 | 65.4 | 6865.5 |
| nov | 3680.8 | 325.4 | 1290.6 | 361.9 | 2783.9 | 2894.8 | 58.9 | 7715.5 |
| dec | 2025.6 | 966.4 | 1231.9 | 466.2 | 3505.4 | 3729.4 | 32.4 | 9931.7 |
| **Annual Total** | **38,219** | **8,438** | **15,311** | **4,444** | **33,003** | **35,550** | **612** | **97,358** |

Figure 21. Estimated annual energy consumption for chilled ceiling model

| | | | |
|---|---|---|---|
| Total electric consumption | = | 97 358 | kWh |
| Total gas consumption | = | 38 219 | kWh |
| $CO_2$ emissions | = | 138 485 | kg |

### 3.5 Chilled Ceilings with 100% Fresh Air Intake

- Chilled ceilings model + 100% fresh air intake

The benefits of constantly introducing fresh air into the space compared with recirculating mixed supply and return air are understood. The flushing out of all warm contaminated air without it mixing greatly increases the level of air quality in the space, which increases health, wellbeing and productivity.

The difference between this and the last chilled ceilings model is that:

1. Fresh air rates for the space have more than doubled from 10L/s/person to 22.5L/s/person
2. Air introduced to the space is 100% fresh air and not a mixture of return and supply air, ie all return air is exhausted.

Similarly, the air handling unit will be powered by a central gas boiler and electric chiller, with air dehumidified to eliminate any risk of condensation on the ceiling panels.

This model will show the effects of 100% fresh air into the space on energy consumption.

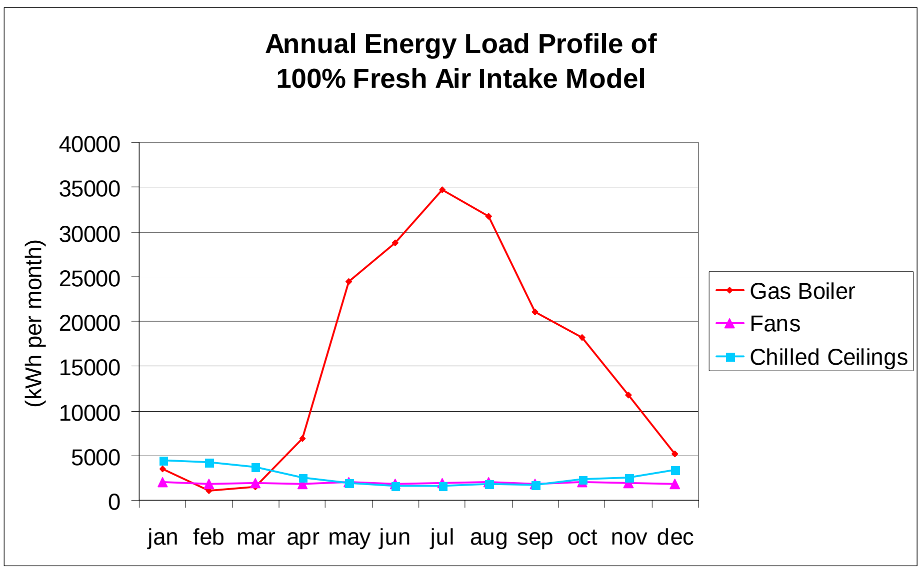


Figure 22. Estimated annual energy load profile for 100% fresh air model

In order to compensate for the continuous fresh air entering the building, we can see that during the colder months, the gas boiler has largely increased its energy consumption as it is constantly warming up cold outside air to maintain required temperature levels. Electric consumption from fans and the chilled ceilings remain similar.

| Month | Gas Boiler Input (kWh) | Chiller Input (kWh) | Fans AHU (kWh) | Fans Cool Tower (kWh) | Elec Ceiling Chiller (kWh) | Water Pumps Chilled (kWh) | Water Pumps Hot (kWh) | Total (kWh) |
|---|---|---|---|---|---|---|---|---|
| jan | 3480.4 | 1812.8 | 2023.4 | 646.1 | 4440.3 | 5169.1 | 55.7 | 14147.4 |
| feb | 1098.1 | 3165.4 | 1759.5 | 751.1 | 4242.9 | 6009 | 17.6 | 15945.5 |
| mar | 1525 | 1351.2 | 1935.5 | 540.5 | 3689.8 | 4324 | 24.4 | 11865.4 |
| apr | 6904.8 | 164.5 | 1847.5 | 306.8 | 2487.4 | 2454.1 | 110.5 | 7370.8 |
| may | 24462.4 | 0 | 2023.4 | 216.5 | 1874.9 | 1732 | 391.4 | 6238.2 |
| jun | 28734.7 | 0 | 1847.5 | 171.6 | 1570 | 1372.8 | 459.8 | 5421.7 |
| jul | 34685.8 | 0 | 1935.5 | 160.8 | 1538 | 1286.1 | 555 | 5475.4 |
| aug | 31694.2 | 0 | 2023.4 | 206.2 | 1817.7 | 1650 | 507.1 | 6204.4 |
| sep | 21015.1 | 0 | 1759.5 | 193.2 | 1659.6 | 1545.2 | 336.2 | 5493.7 |
| oct | 18201.9 | 9.6 | 2023.4 | 283 | 2296.4 | 2264 | 291.2 | 7167.6 |
| nov | 11762.4 | 111.3 | 1935.5 | 319.1 | 2538 | 2552.8 | 188.2 | 7644.9 |
| dec | 5170.5 | 750.5 | 1847.5 | 450.2 | 3370.7 | 3601.5 | 82.7 | 10103.1 |
| **Annual Total** | **188,735** | **7,365** | **22,962** | **4,245** | **31,526** | **33,961** | **3,020** | **103,078** |

Figure 23. Estimated annual energy consumption for 100% fresh air model

| | | | |
|---|---|---|---|
| Total electric consumption | = | 103 078 | kWh |
| Total gas consumption | = | 188 735 | kWh |
| $C0_2$ emissions | = | 177 759 | kg |

### 3.6 Phase Change Materials (PCMs)

Phase Change Materials (PCMs) are compounds which melt and solidify, ie perform a phase change, at certain temperatures and in doing so are capable of storing and releasing large amounts of energy. Put simply, PCMs will store the coolness of the night and use it to cool the building during the day.

The Phase Change Material (PCM) model makes one change to the previous chilled ceilings/beams model in that it uses a different fuel or energy source to provide most of the cooling requirements to the chilled ceilings/beams. Fresh air will still be cooled or heated by the central chiller and boiler respectively.

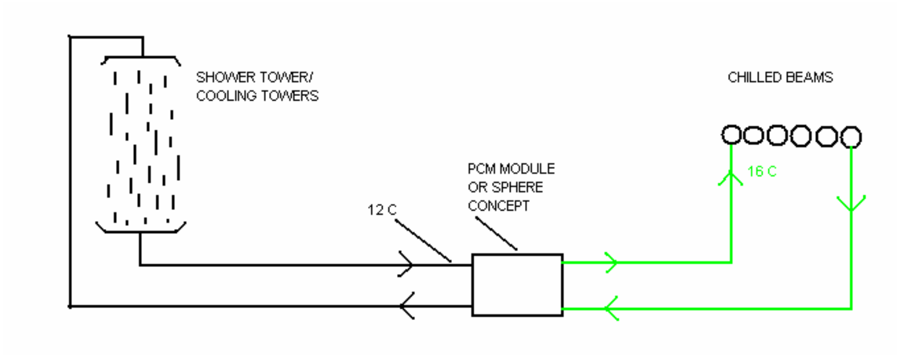


Figure 24. Basic Phase Change Material (PCM) schematic

A storage tank containing the PCMs, used in conjunction with cooling and shower towers, will be connected to the chilled ceiling/beam system. Electric chillers used previously will be fully compensated by PCMs as a means to cool the ceilings/beams.

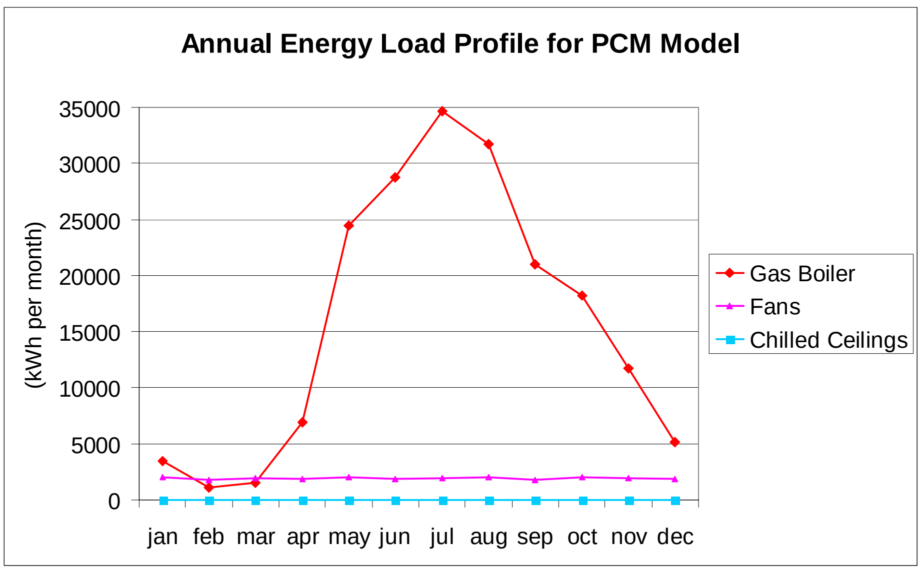


Figure 25. Estimated annual energy load profile for the PCM model

With the use of PCMs, the electric power used to previously cool the chilled ceilings and beams via a chiller has been completely eliminated. However, the gas boiler, chiller, and fan consumption remains the same because the fresh air system does not change.

| Month | Gas Boiler Input (kWh) | Chiller Input (kWh) | Fans AHU (kWh) | Fans Cool Tower (kWh) | Elec Ceiling Chiller (kWh) | Water Pumps Condenser (kWh) | Water Pumps Chilled (kWh) | Water Pumps Hot (kWh) | Total (kWh) |
|---|---|---|---|---|---|---|---|---|---|
| jan | 3480.4 | 1812.8 | 2023.4 | ~ | 0 | ~ | 5169.1 | 55.7 | ~ |
| feb | 1098.1 | 3165.4 | 1759.5 | ~ | 0 | ~ | 6009 | 17.6 | ~ |
| mar | 1525 | 1351.2 | 1935.5 | ~ | 0 | ~ | 4324 | 24.4 | ~ |
| apr | 6904.8 | 164.5 | 1847.5 | ~ | 0 | ~ | 2454.1 | 110.5 | ~ |
| may | 24462.4 | 0 | 2023.4 | ~ | 0 | ~ | 1732 | 391.4 | ~ |
| jun | 28734.7 | 0 | 1847.5 | ~ | 0 | ~ | 1372.8 | 459.8 | ~ |
| jul | 34685.8 | 0 | 1935.5 | ~ | 0 | ~ | 1286.1 | 555 | ~ |
| aug | 31694.2 | 0 | 2023.4 | ~ | 0 | ~ | 1650 | 507.1 | ~ |
| sep | 21015.1 | 0 | 1759.5 | ~ | 0 | ~ | 1545.2 | 336.2 | ~ |
| oct | 18201.9 | 9.6 | 2023.4 | ~ | 0 | ~ | 2264 | 291.2 | ~ |
| nov | 11762.4 | 111.3 | 1935.5 | ~ | 0 | ~ | 2552.8 | 188.2 | ~ |
| dec | 5170.5 | 750.5 | 1847.5 | ~ | 0 | ~ | 3601.5 | 82.7 | ~ |
| **Annual Total** | **188,735** | **7,365** | **22,962** | **4,017** | **0** | **1,339** | **33,961** | **3,020** | **72,663** |

Figure 26. Estimated annual energy consumption for PCM model

| | | | |
|---|---|---|---|
| Total electric consumption | = | 72 663 | kWh |
| Total gas consumption | = | 188 735 | kWh |
| $CO_2$ emissions | = | 137 003 | kg |

### 3.7 Co-generation Plant

The co-generation plant for Melbourne City Council produces a portion of the building's electricity requirement through the consumption of natural gas which produces waste heat that can be utilised. The use of natural gas turbine technology also delivers increased fuel efficiency benefits and lowers $CO_2$ emissions. This is due to natural gas being much cleaner than a coal powered source of electricity (from the provider network grid) which would otherwise be used.

It is the utilisation of this waste heat which will reduce the energy consumption of the building as a whole and reduce carbon emissions. Waste heat will be utilised to heat or cool fresh air constantly entering the building, partly reducing the building's total energy consumption.

Figure 27. Gas fired co-generation plant at Macquarie University, NSW. Source SEDA

The difference between this and the previous model is that any cooling/heating load 100kW or less is powered by waste heat from the co-generation plant to directly heat or indirectly cool (via an absorption chiller) fresh air. This model sizes the co-generation plant at an optimum 100kW waste heat capacity.

It is assumed that any cooling/heating loads above 100kW will be powered through an absorption chiller fuelled by gas. Another option is to purchase electricity from a network provider to supplement the chiller loads instead.

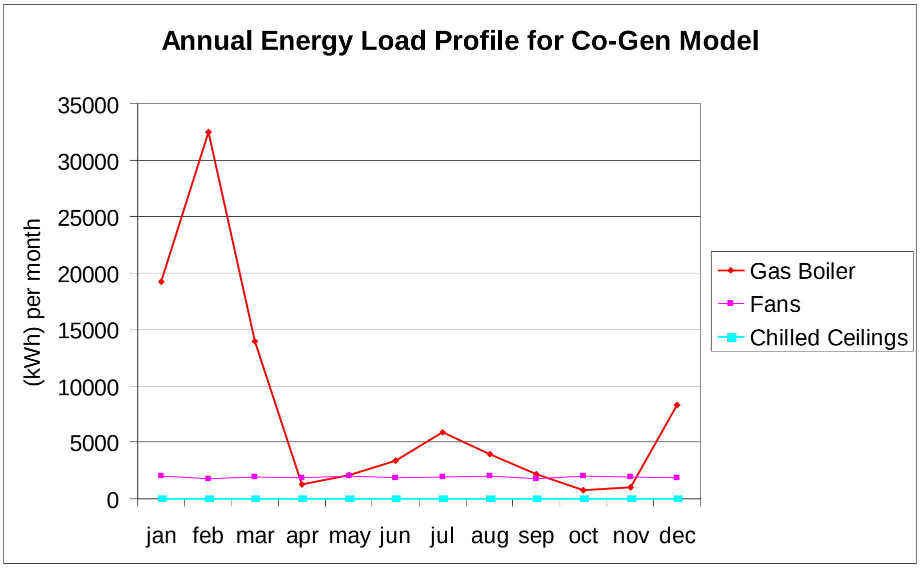


Figure 28. Estimated annual energy load profile for co-generation model

As a result, gas boiler consumption has dropped considerably to about one quarter of its previous usage which will cause major impacts in energy consumption and especially in carbon emission reduction. Notice that in summer, gas boiler requirements are significant due to large cooling loads demanded from the absorption chiller.

| Month | Gas Boiler Input (kWh) | Chiller Input (kWh) | Fans AHU (kWh) | Fans Cool Tower (kWh) | Elec Ceiling Chiller (kWh) | Water Pumps Condenser (kWh) | Water Pumps Chilled (kWh) | Water Pumps Hot (kWh) | Total (kWh) |
|---|---|---|---|---|---|---|---|---|---|
| jan | 19187.8 | 1812.8 | 2023.4 | ~ | 0 | ~ | 5169.1 | 55.7 | ~ |
| feb | 32513.01 | 3165.4 | 1759.5 | ~ | 0 | ~ | 6009 | 17.6 | ~ |
| mar | 13941.53 | 1351.2 | 1935.5 | ~ | 0 | ~ | 4324 | 24.4 | ~ |
| apr | 1286.14 | 164.5 | 1847.5 | ~ | 0 | ~ | 2454.1 | 110.5 | ~ |
| may | 2117.48 | 0 | 2023.4 | ~ | 0 | ~ | 1732 | 391.4 | ~ |
| jun | 3378.47 | 0 | 1847.5 | ~ | 0 | ~ | 1372.8 | 459.8 | ~ |
| jul | 5836.12 | 0 | 1935.5 | ~ | 0 | ~ | 1286.1 | 555 | ~ |
| aug | 3940.07 | 0 | 2023.4 | ~ | 0 | ~ | 1650 | 507.1 | ~ |
| sep | 2162.95 | 0 | 1759.5 | ~ | 0 | ~ | 1545.2 | 336.2 | ~ |
| oct | 768.11 | 9.6 | 2023.4 | ~ | 0 | ~ | 2264 | 291.2 | ~ |
| nov | 1023.44 | 111.3 | 1935.5 | ~ | 0 | ~ | 2552.8 | 188.2 | ~ |
| dec | 8271.42 | 750.5 | 1847.5 | ~ | 0 | ~ | 3601.5 | 82.7 | ~ |
| **Annual Total** | **94,427** | **7,365** | **22,962** | **4,017** | **0** | **1,339** | **33,961** | **3,020** | **72,663** |

Figure 29. Estimated annual energy consumption for co-generation model

| | | | |
|---|---|---|---|
| Total electric consumption | = | 72 663 | kWh |
| Total gas consumption | = | 94 427 | kWh |
| $CO_2$ emissions | = | 117 198 | kg |

## 3.8 Model Comparisons

### 3.8.1 Energy consumption

The graph below shows the comparison of electricity and gas consumption used by the heating ventilation air conditioning system for all models.

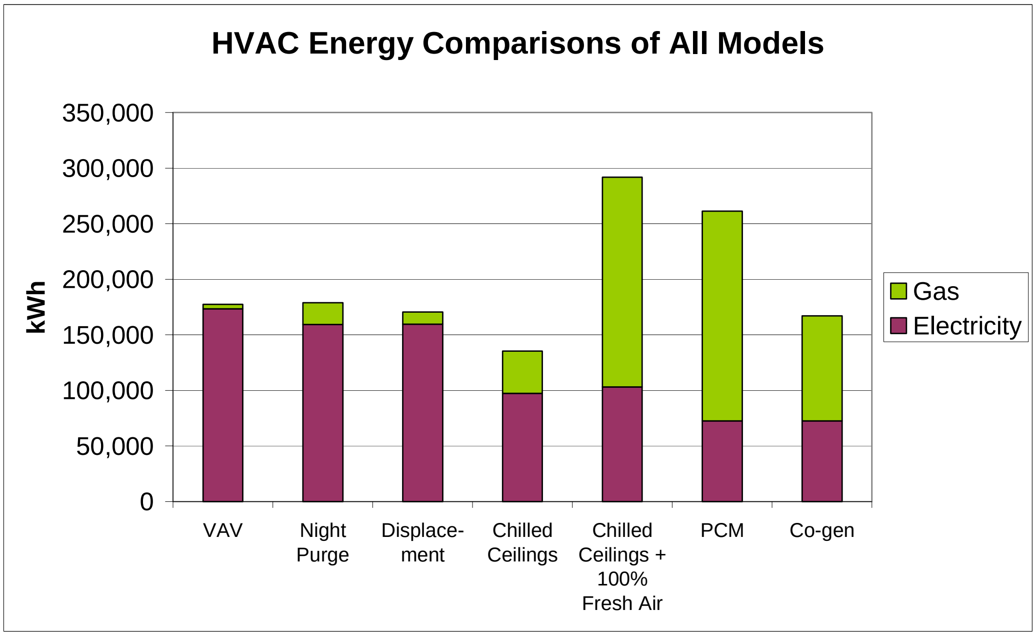


Figure 30. Energy comparison of all models

Although the use of night purge, displacement, chilled ceilings, 100% fresh air intake and phase change materials has contributed to the decrease in electricity usage, it has also brought about a significant increase in gas consumption. Overall, this manages to reduce carbon emissions by 27% because gas is six times cleaner than electricity as an energy source.

However, through the use of waste heat from a co-generation plant, the increase in energy consumption has been offset completely. The energy consumption of the final model is less than that of the base model. These impacts are even greater when we compare carbon emissions.

### 3.8.2 Carbon emissions

The objective of a 'green' building is to minimise the emission of greenhouse gases, namely carbon dioxide emissions through efficient energy usage. This is will be dependent on energy utilisation between sources such as electricity, gas, solar, wind or energy from a co-generation plant, etc.

In the state of Victoria, Australia, gas has a $CO_2$ co-efficient of 0.21 which is much less than the 1.34 co-efficient for electricity. This means that electricity pollutes about 6.4 times more than gas and electricity usage is most undesirable.

Using these co-efficients, we can calculate carbon emissions for each model and the following comparative graph can be produced.

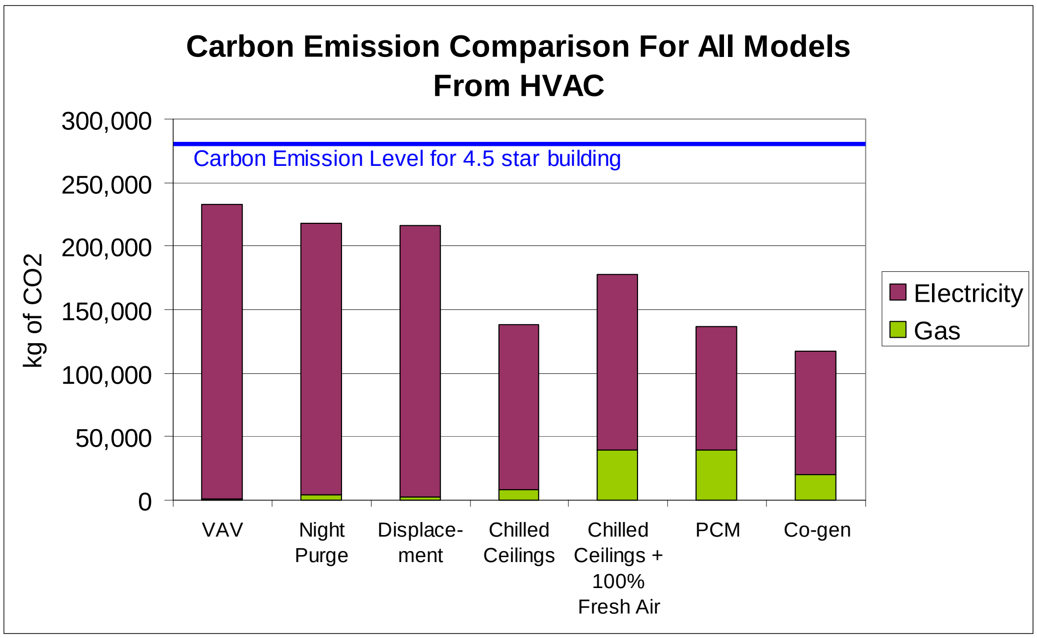


Figure 31. Carbon emission comparison of all models

We can see that the last model which adopts a co-generation plant into a chilled ceilings/beam air conditioning system (with displacement air and night purge benefits) by far produces the least amount of carbon dioxide emissions. This is 44% of what a 4.5 star building would normally achieve under the Australian Building Greenhouse Rating scheme. The adoption of LCD flat screen monitors, which reduce cooling loads by around 12%, will bring this consumption down even further.

# 4 CONCLUSIONS AND RECOMMENDATIONS

It is apparent that the chilled ceiling/beam system with 100% fresh air exceeds the traditional VAV model in advantages such as the following, which also improve on cost effectiveness:

- *Carbon emissions* – reducing $CO_2$ emissions to 44% of a 4.5 star building
- *Air quality* – by providing 100% fresh, non-recycled air, as well as using the benefits of displacement ventilation to flush warm contaminated air out instead of mixing it within the space
- *Equality of access* – all occupants have access to the cool ceiling above and floor vents are evenly distributed which passively proves a more even temperature throughout the space
- *Increased productivity* – through the reduction of noise, the increase in air quality, and the even distribution of cool air, occupants are healthier, more comfortable, have an increased state of wellbeing and are more productive.
- *Maintenance* – is much less for chilled ceiling system as there are less moving parts
- *Increased lifespan* – the chilled ceiling system has an increased lifespan because of reduced plant loads and less maintenance problems
- *Space saving* – chilled ceilings eliminate the need for high volume ductwork, minimising ceiling voids requirements and increasing opportunities for refurbishment as well as increasing Net Lettable Areas opportunities
- *Energy efficiency*. Friction losses and lagging are eliminated by the system and the building fabric contributes to the cooling system.

Figure 32. Chilled ceiling panels in Cannons, Covent Garden. Source SAS International

To improve the energy benefits even further, it is also recommended that

- phase change materials be used to partially power the chilled ceilings/beams system
- waste heat from an economically sized co-generation plant (100kW used for modelling) be utilised to reduce on cooling and heating loads

Based on major benefits in health, performance, energy consumption and carbon emissions, it is recommended that the use of night purge, displacement ventilation, chilled ceilings/beams, phase change materials and waste heat from a co-generation plant, be used for the new Melbourne City Council Offices.

Through excellent energy utilisation and energy consumption reduction, an extremely high standard of 'green building' has been achieved. The new Melbourne City Council House will reduce carbon emissions to only 44% of a 4.5 star building under the Australian Building Greenhouse Rating scheme, expected to drop even further through the adoption of LCD flat screen monitors.

Figure 33. Ventilation stacks, Solar Energy Research Facility, Colorado. Source NREL.